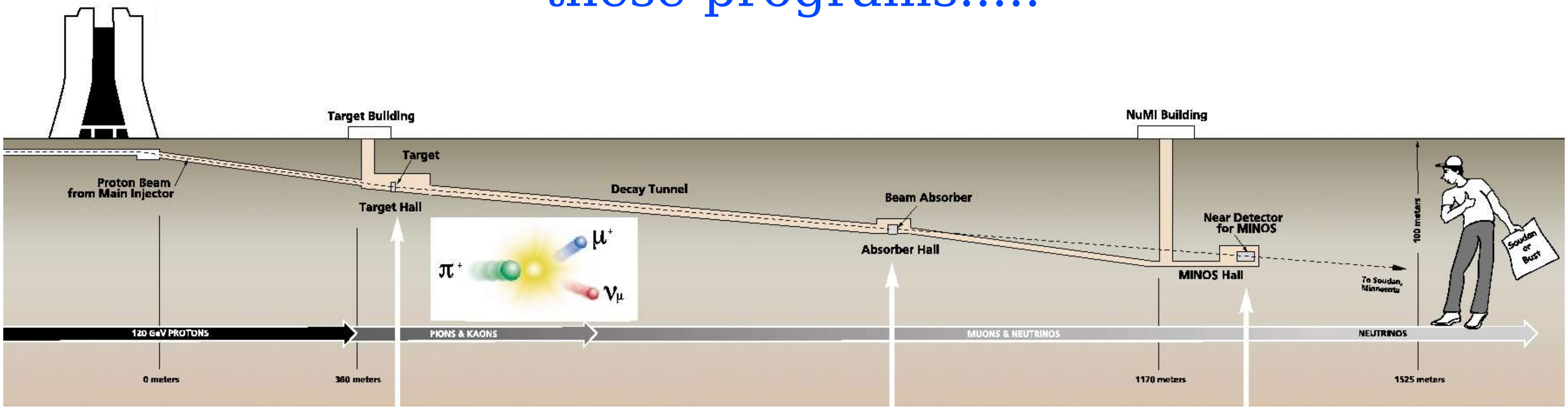
Bonnie Fleming
PANIC satellite mtg
October 30th, 2005

Liquid Argon Detectors for Long Baseline Neutrino Physics

Long-baseline neutrino physics provides a window into neutrino oscillation physics

hierarchy of the neutrino masses, structure of the mixing matrix, CP Violation in the neutrino sector

New high intensity sources available for these programs.....



Limiting factor in sensitivity for long-baseline neutrino physics is ν_e event rate and background rejection

Massive LArTPCs provide excellent means to do this physics

- Improved efficiencies and background rejection ameliorate statistics limitations of long-baseline neutrino physics
- Success of the ICARUS T600 proves technical feasibility for “small” detectors

  - How much better are they?
  - Can we build these detectors?

→ focus on efforts at FNAL, but there are also efforts at T2K and CNGS

LArTPC's report to NuSAG*

www-lartpc.fnal.gov

Fermilab Note: **FN-0776-E**

A Large Liquid Argon Time Projection Chamber for Long-baseline, Off-Axis
Neutrino Oscillation Physics with the NuMI Beam
Submission to NuSAG
September 15, 2005

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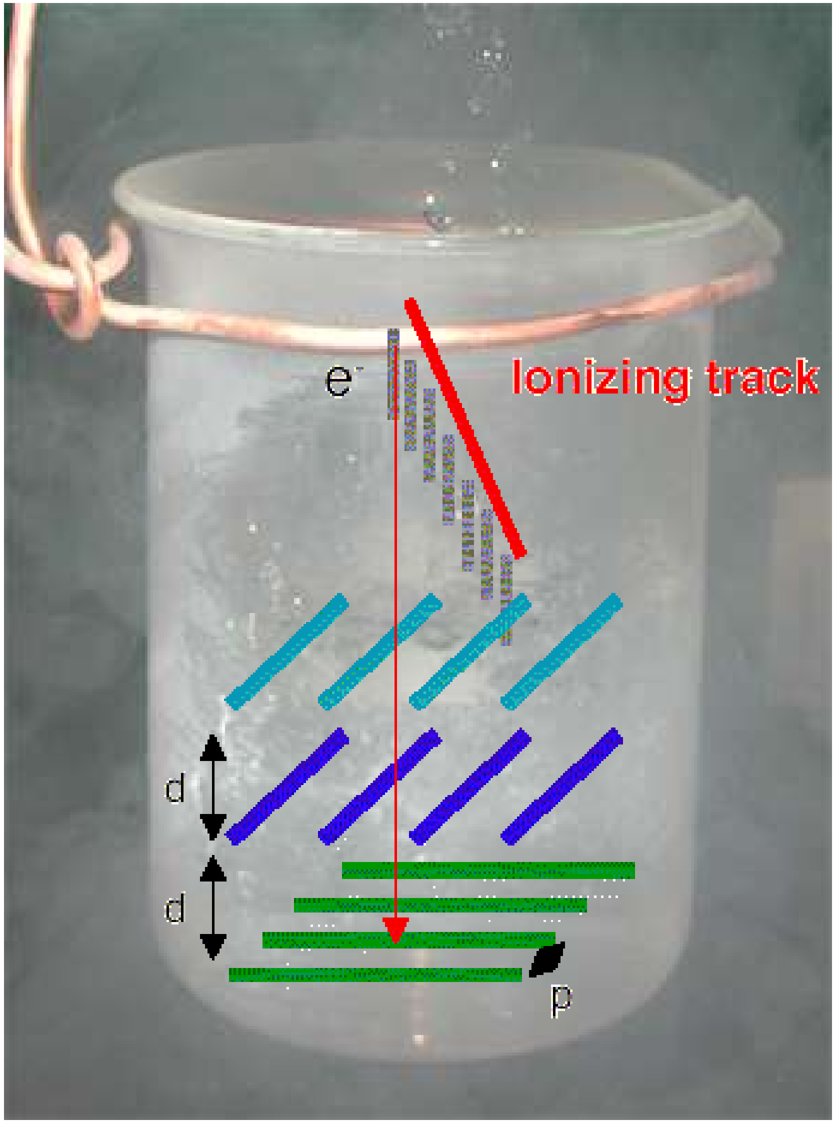
S. Menary
York University

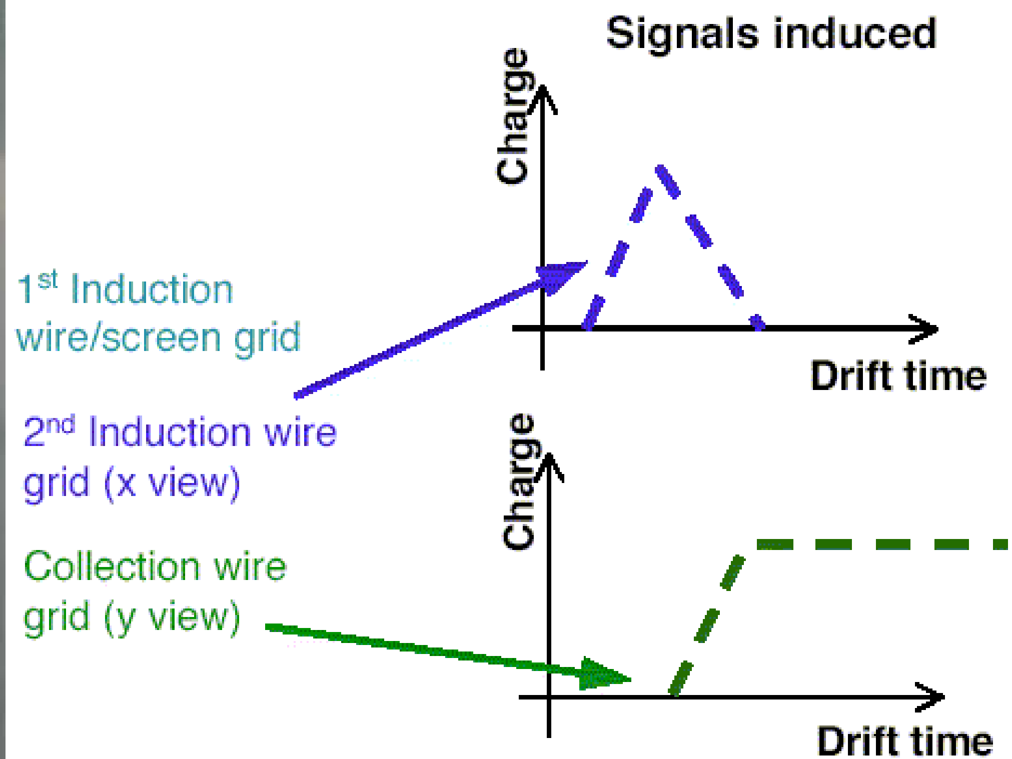
Contact Persons: B. T. Fleming and P. A. Rapidis

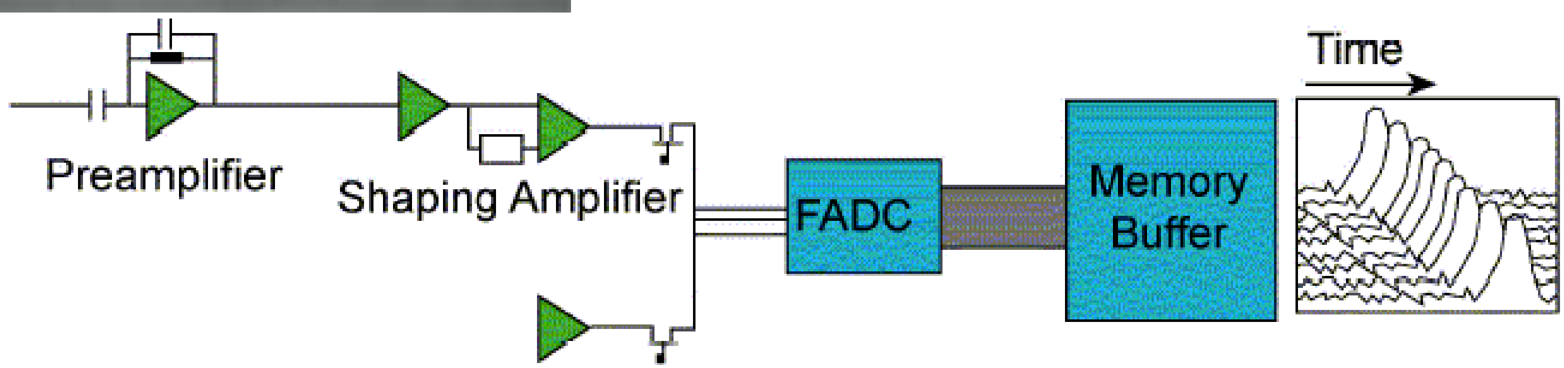
Interest in the community as per NuSAG's charge

* The ***N**e**u**trino* ***S**cientific **A**ssessment* ***G**roup for the DOE/NSF*

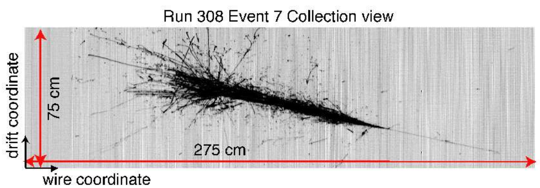
Liquid Argon TPC

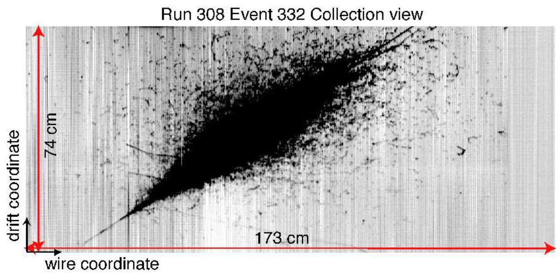


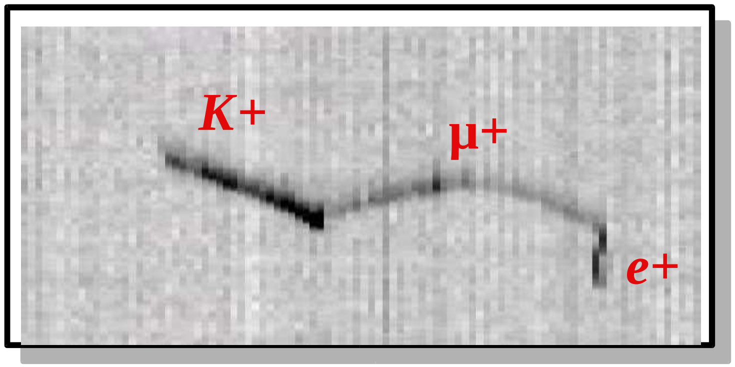




Allows for high resolution imaging like bubble chambers, but with calorimetry and continuous digital readout (no deadtime)

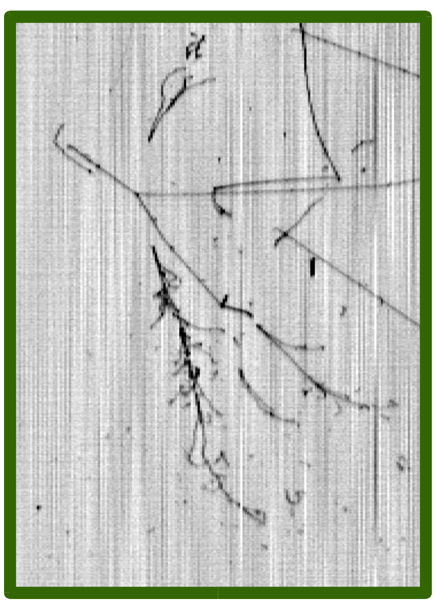


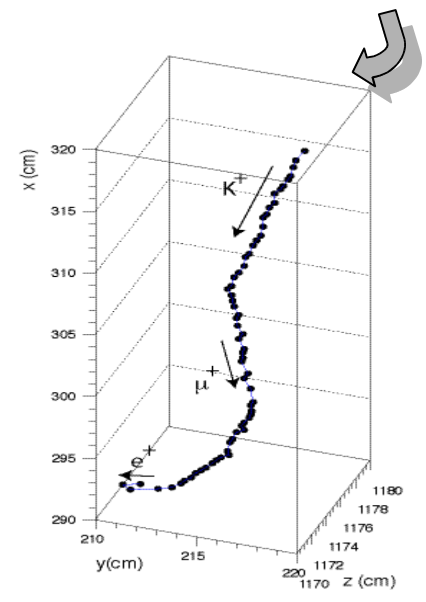




data

data





3D representation of data event

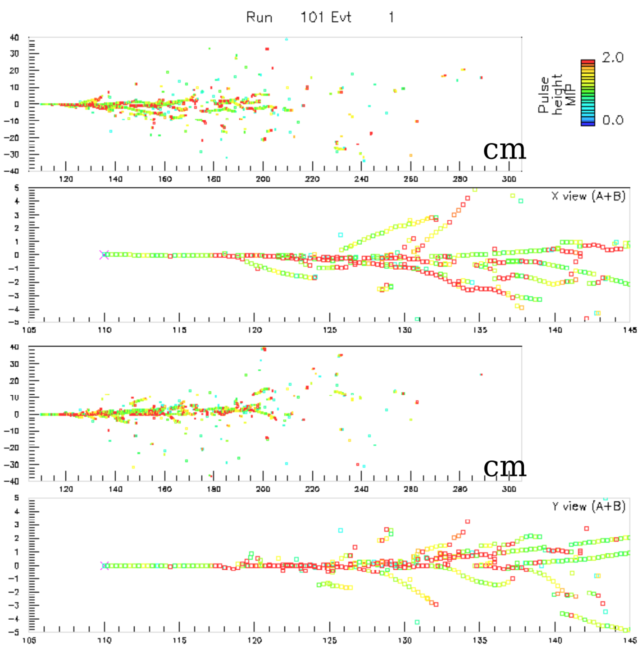
ICARUS images

Electrons versus π^0's at 1.5 GeV

Dot indicates hit
color indicates collected charge
green=1 mip, red=2 mips

X plane → zoom in

Y plane → zoom in

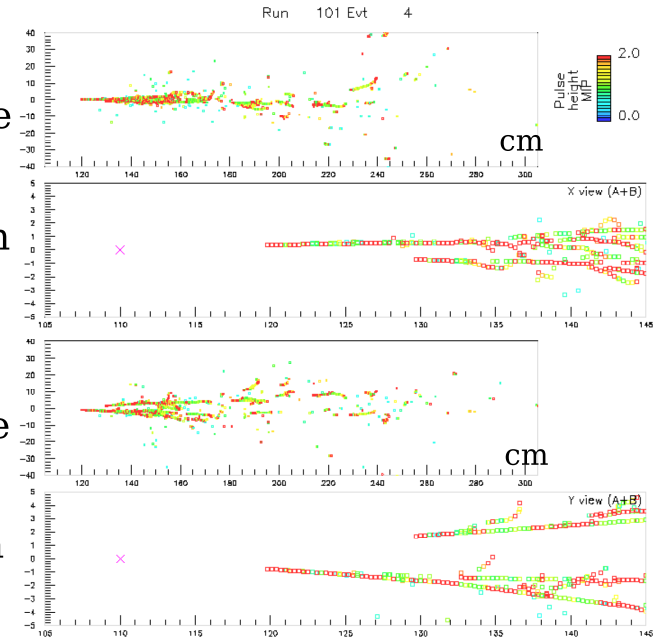


Electrons

Single track (mip scale) starting from a single vertex

X plane → zoom in

Y plane → zoom in



π^0

Multiple secondary tracks can be traced back to the same primary vertex

Each track is two electrons – 2 mip scale per hit

Use both topology and dE/dx to identify interactions

Neutral current event with 1 GeV π^0

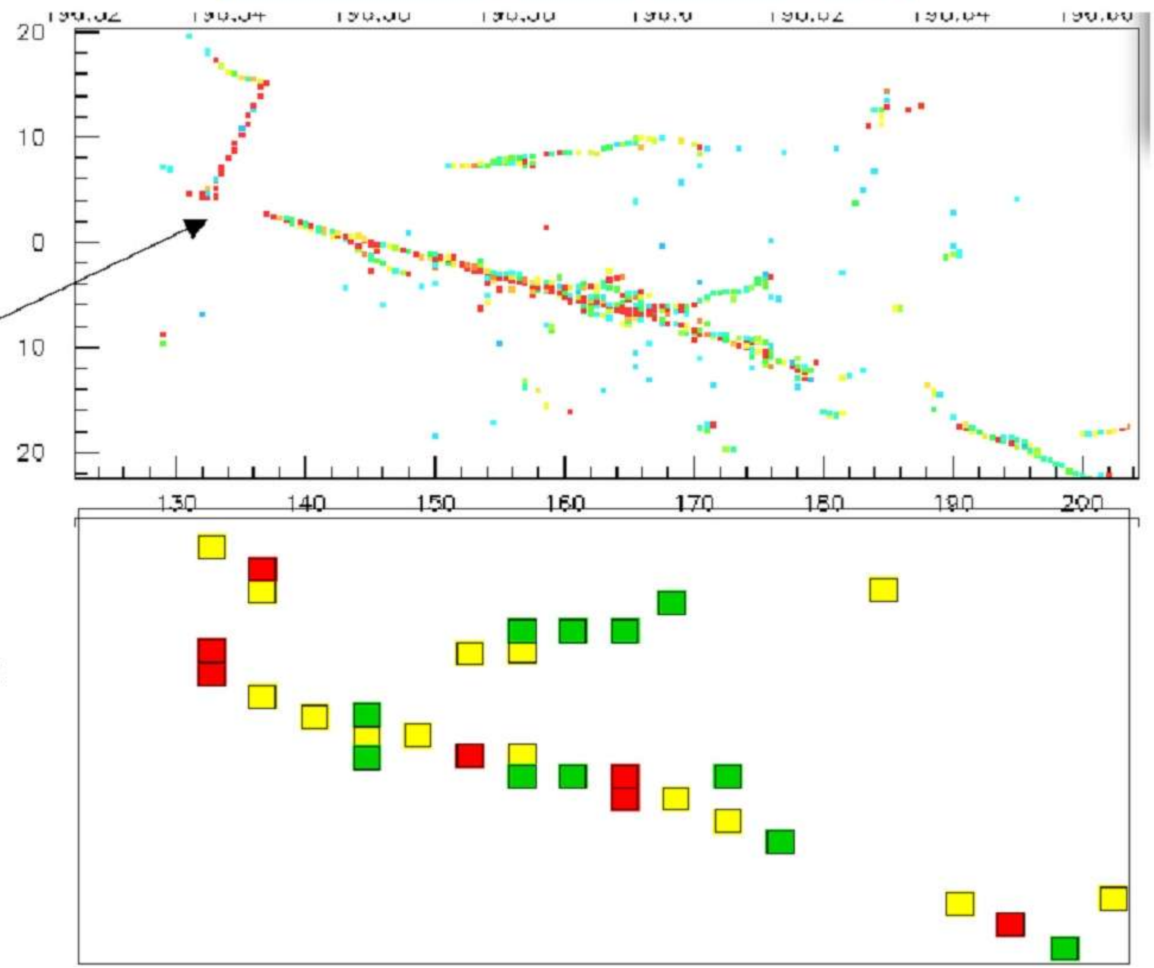
$$\nu_\mu + \mathrm{n} \rightarrow \nu_\mu + \pi^+ + \pi^- + \pi^0 + \mathrm{n}$$

$$(1\ \mathrm{GeV})\ \pi^0 \rightarrow \gamma + \gamma$$

3.5% X_0 samples

in all 3 views

4 cm gap



12% X_0 samples

alternating x-y

Efficiency and rejection study

Tufts University Group

Analysis was based on a blind scan of 450 events, carried out by 4 undergraduates with additional scanning of "signal" events by experts.

Neutrino event generator: NEUGEN3, used by MINOS/ NOvA collaboration (and others)
Hugh Gallagher (Tufts) is the principal author.

GEANT 3 detector simulation (Hatcher, Para): trace resulting particles through a homogeneous volume of liquid argon. Store energy deposits in thin slices.

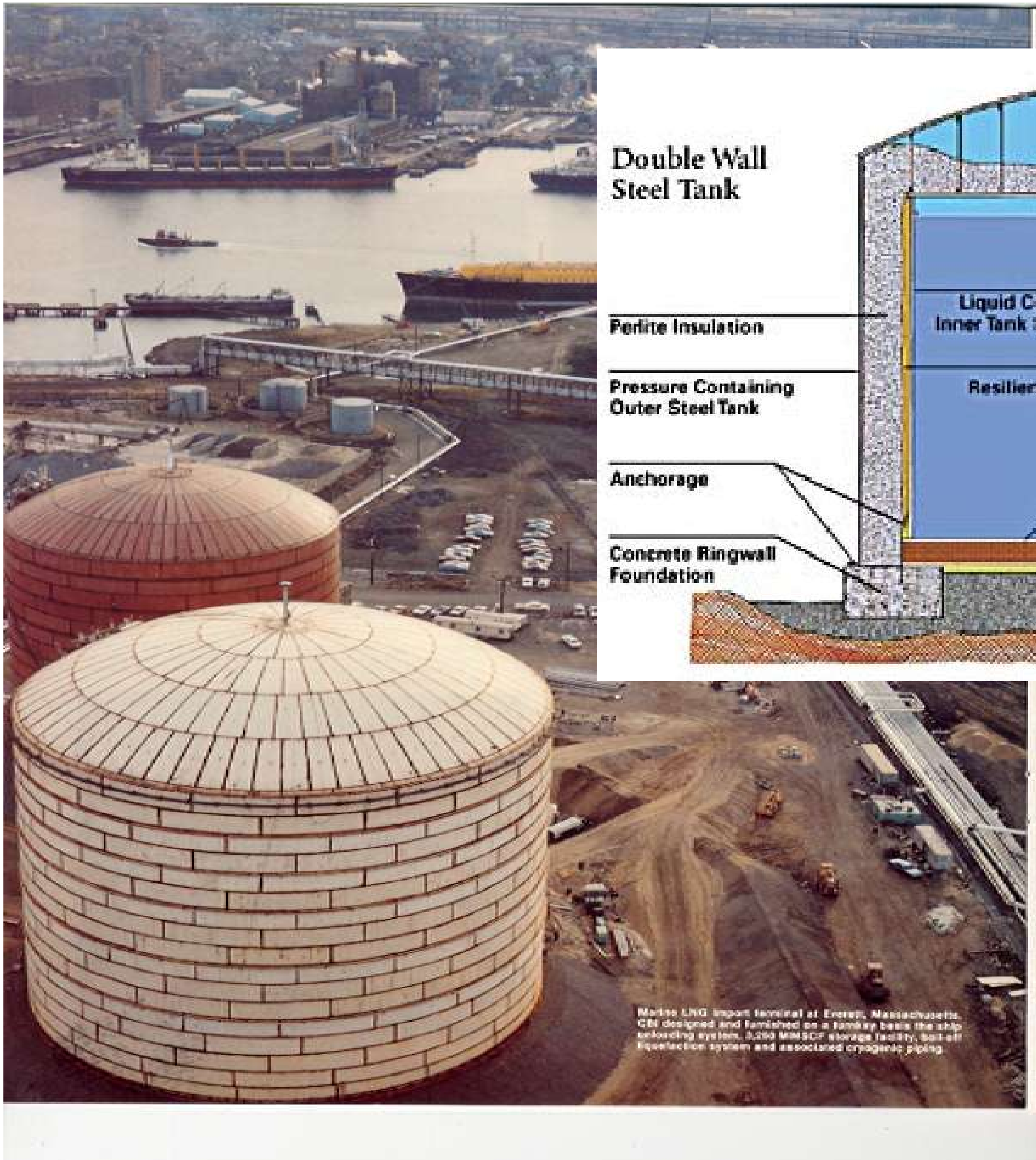
signal efficiency **background rejection**

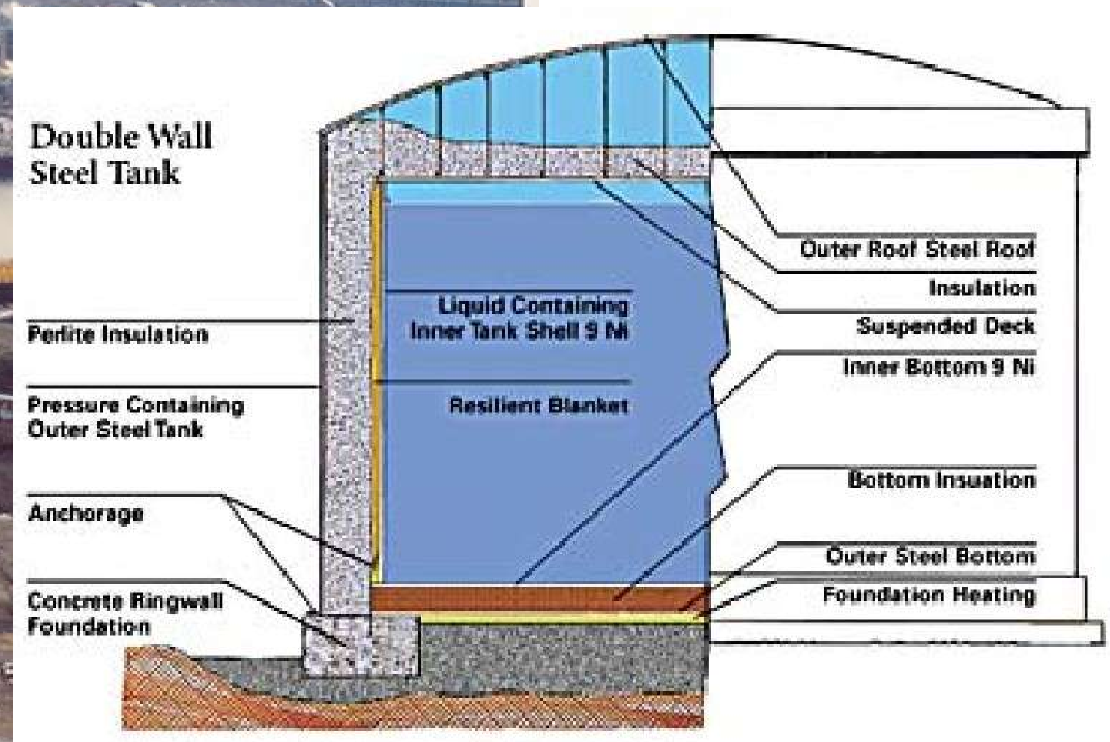
Event Type		N	pass	ϵ	η
NC		290	4	-	0.99±0.01
signal ν_e	CC	32	26	0.81±0.07	-
Beam ν_e	CC	24	14	0.58±0.10	-
Beam ν_e	NC	8	0	-	/
Beam $\overline{\nu}_e$	CC	13	10	0.77 ± 0.09	-
Beam $\overline{\nu}_e$	NC	19	0	-	/
ν_μ	CC	32	0	-	/
$\overline{\nu}_\mu$	CC	32	1	-	/

99.8% NC rejection efficiency

Good signal efficiency (81±7)%

Can we build these detectors?



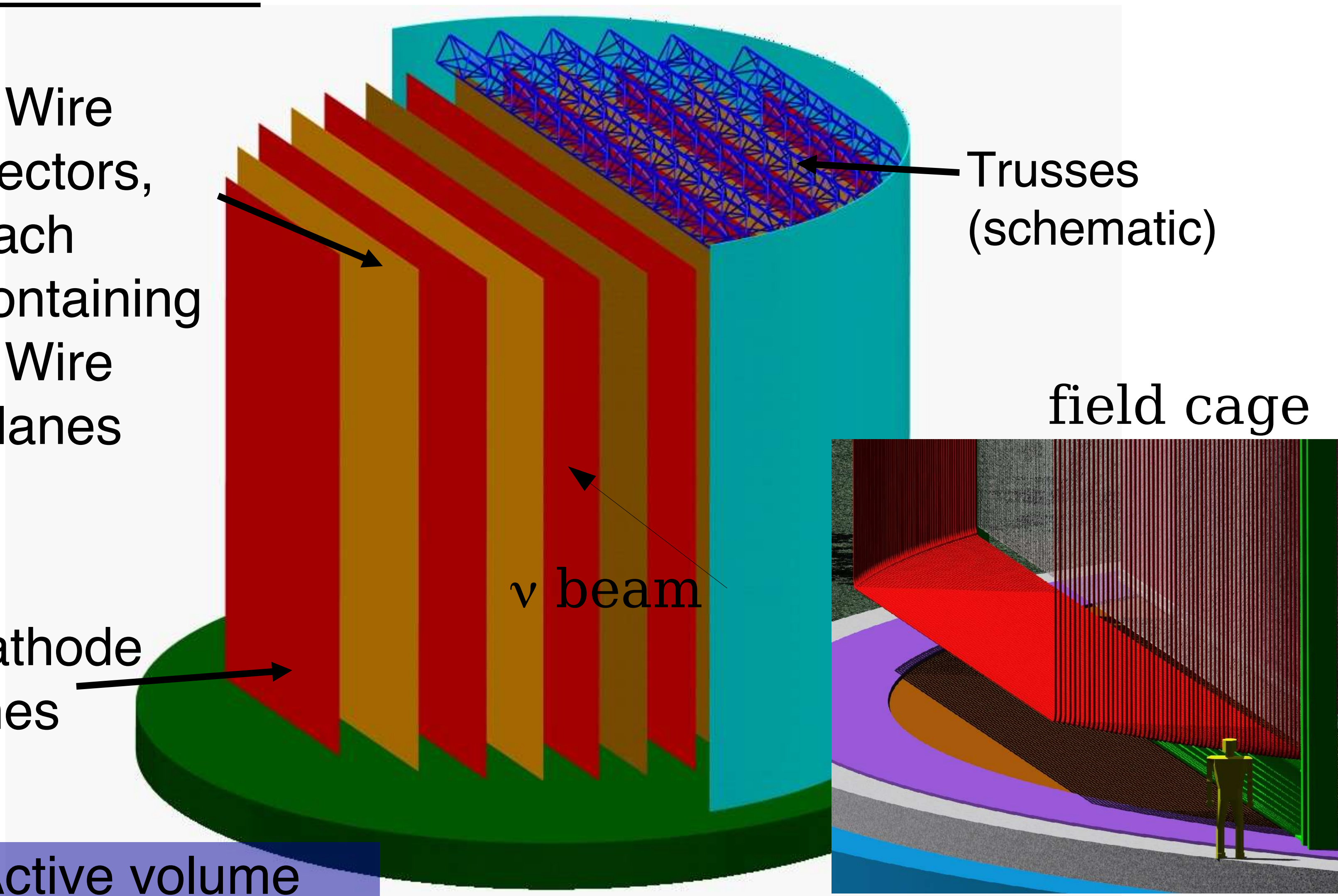


Many large LNG tanks in service

Excellent safety record

Last failure in 1940 understood

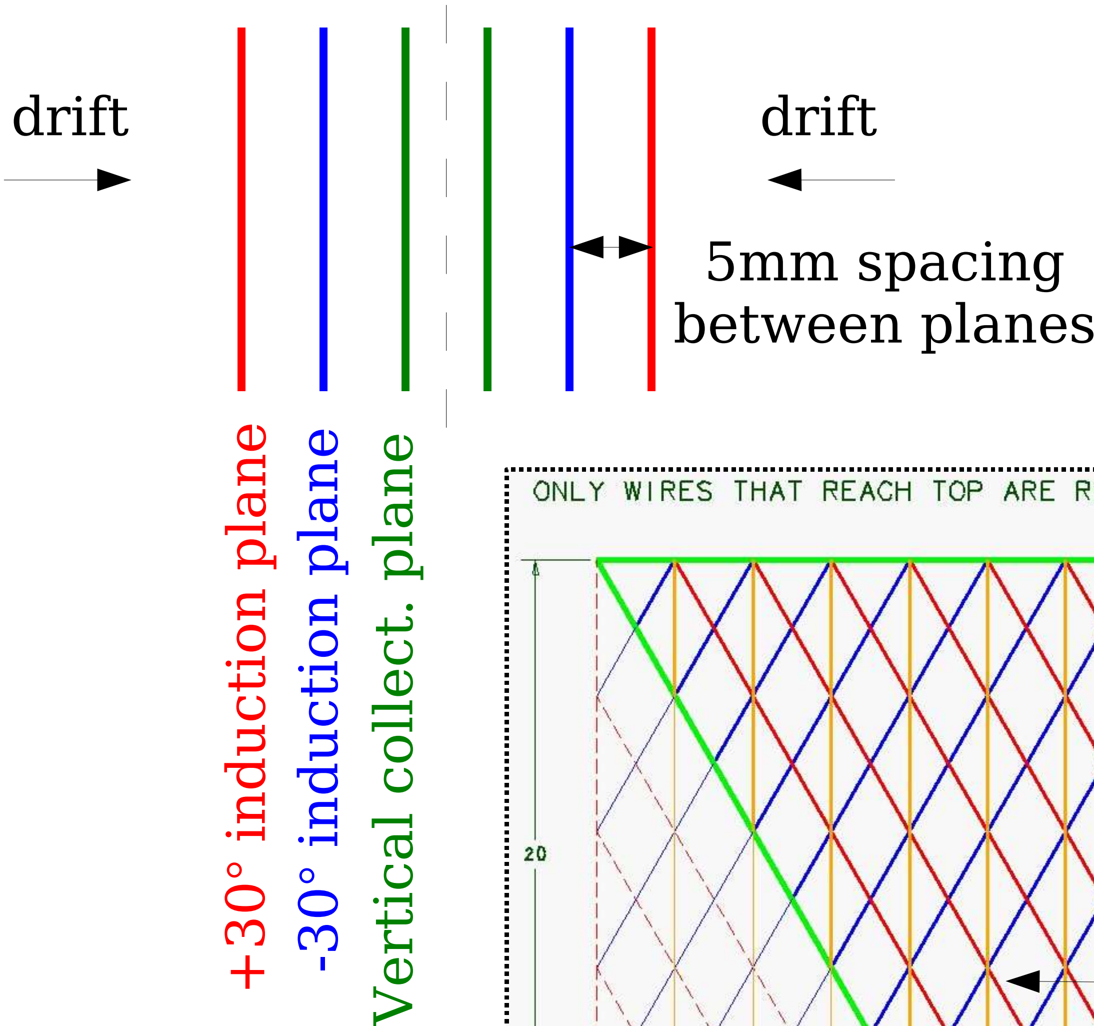
Overview



Active volume
Diameter: 40m
Height: 30m

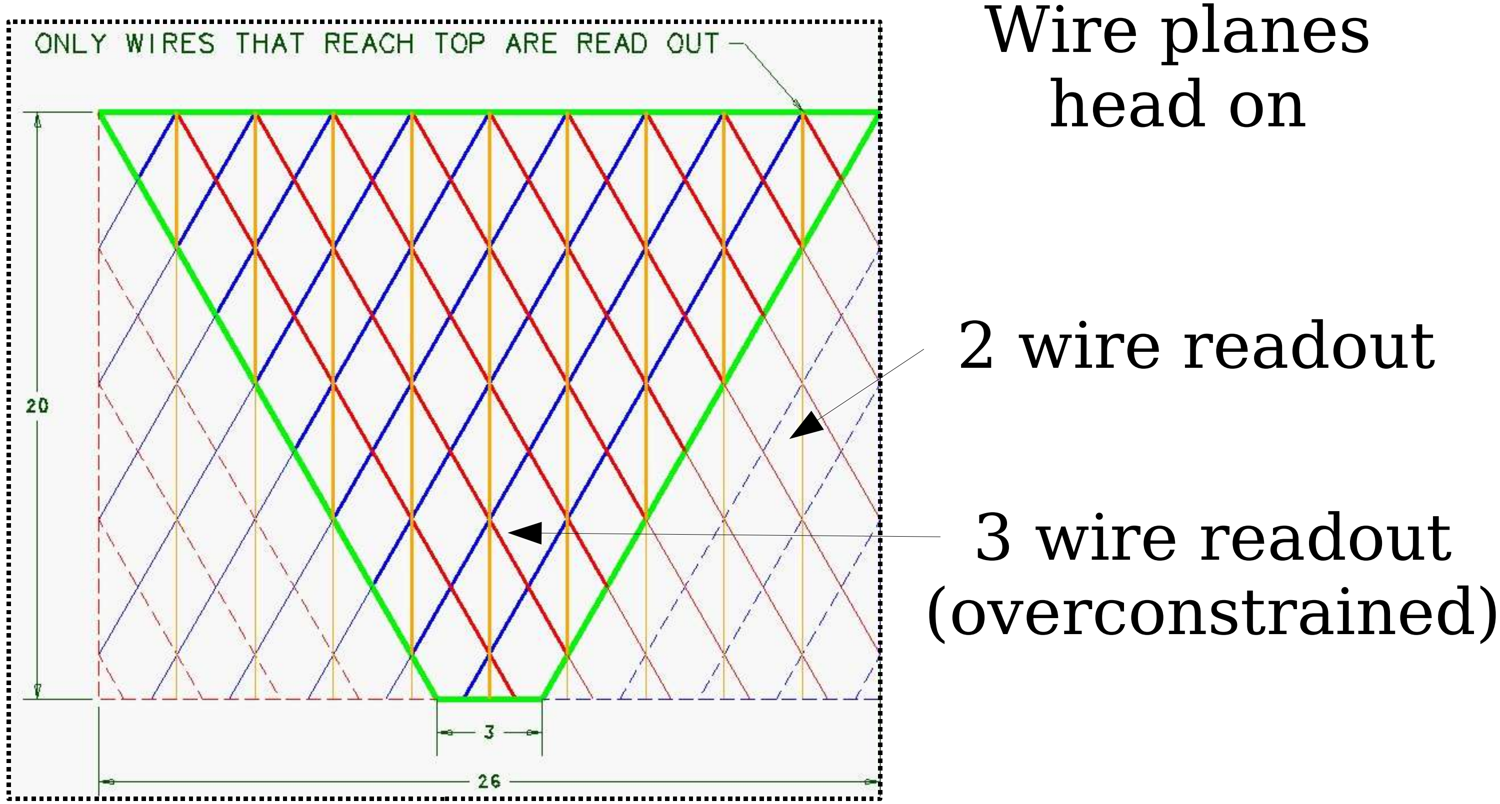
Scalable → 15-50 kTons
4 - 6 wire planes

Each wire plane:



Wires are
- 150 μm stainless steel
- 5mm pitch
- 23m long (15kton)
  35m (50kton)
- 100K total (15kton)
  220K (50kton)

Wire planes head on



Electrons drift 1.5m/ms (150kV field) over 3m drift region

Challenges for massive detector

Purity:

3 m drift in LAr

purification - starting from atmosphere (cannot evacuate detector tank)
- effect of tank walls & non-clean-room assembly process

Wire-planes:

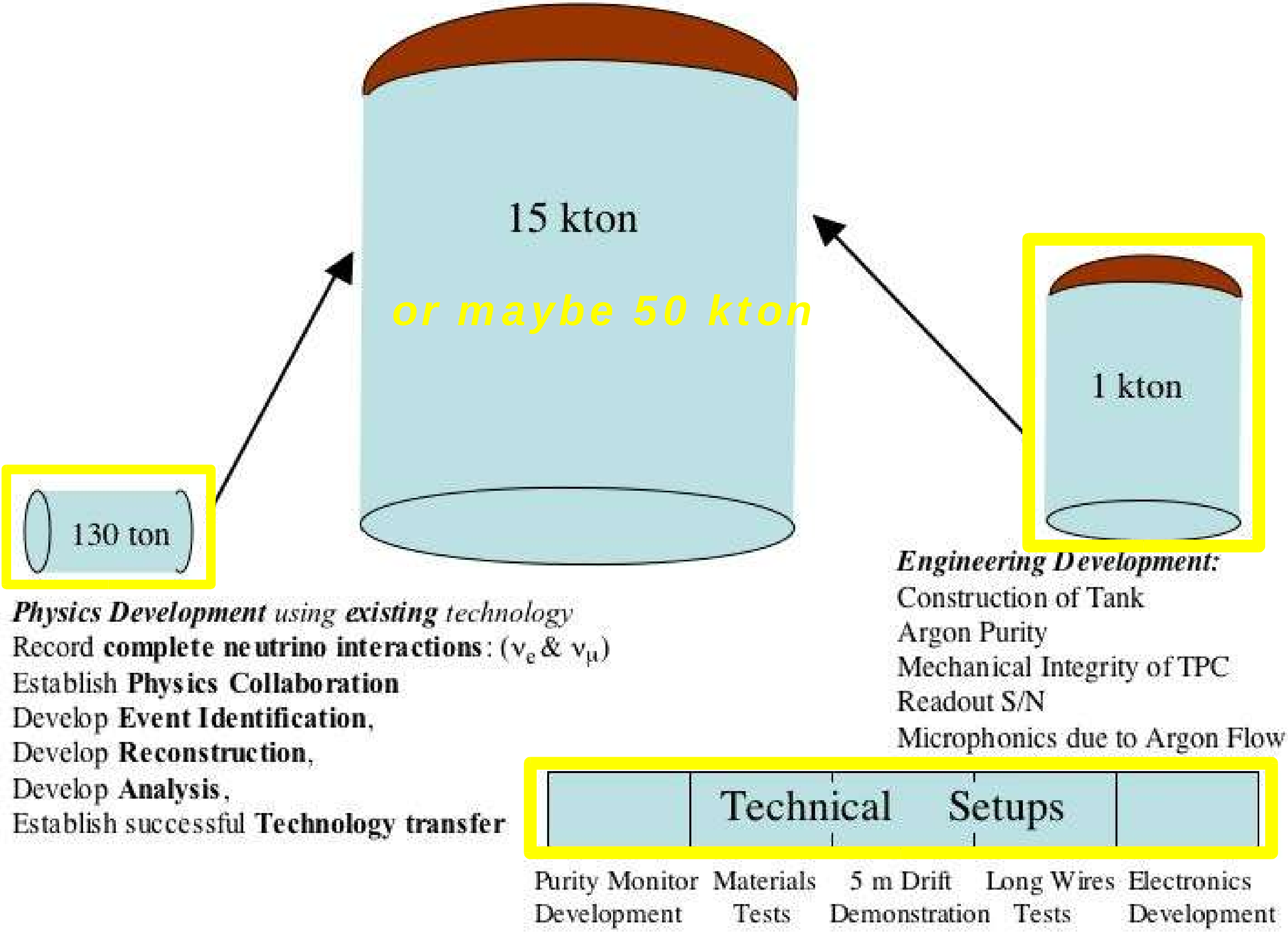
***long wires** - mechanical robustness, tensioning, assembly, breakage/failure*

Signal processing:

***electronics** - noise due to long wire and connection cables (large capacitance)*

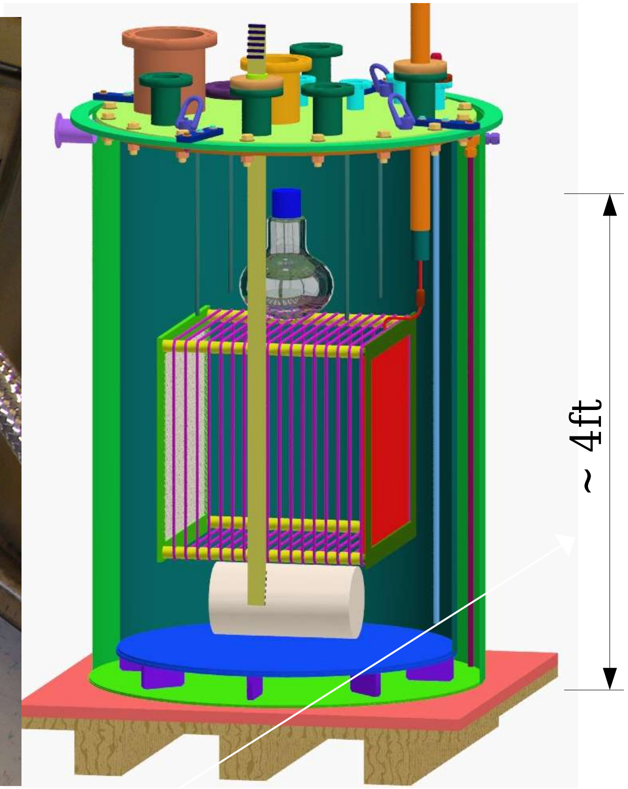
surface detector - data-rates,
- automated cosmic ray rejection
- automated event recognition and reconstruction

Addressing the challenges: The R&D path



LAr TPC Test Setup @ Yale

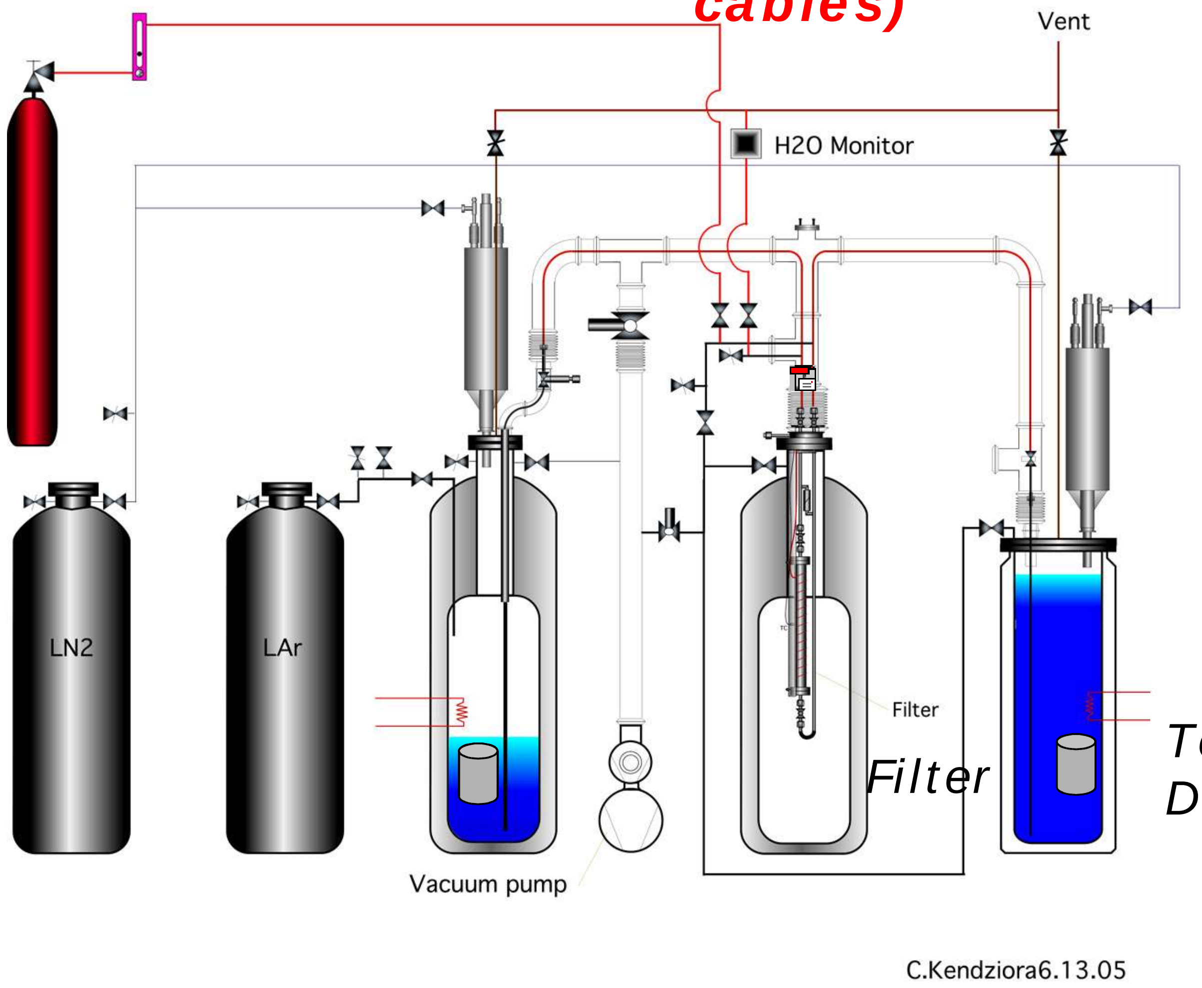
Purity monitor in liquid argon



Purity and light collection

Material tests

System at Fermilab for testing filter materials and the contaminating effects of detector materials (e.g. tank-walls, cables)



ICARUS purity monitor

G. Carugno et al., NIM. A292 (1990

Filter

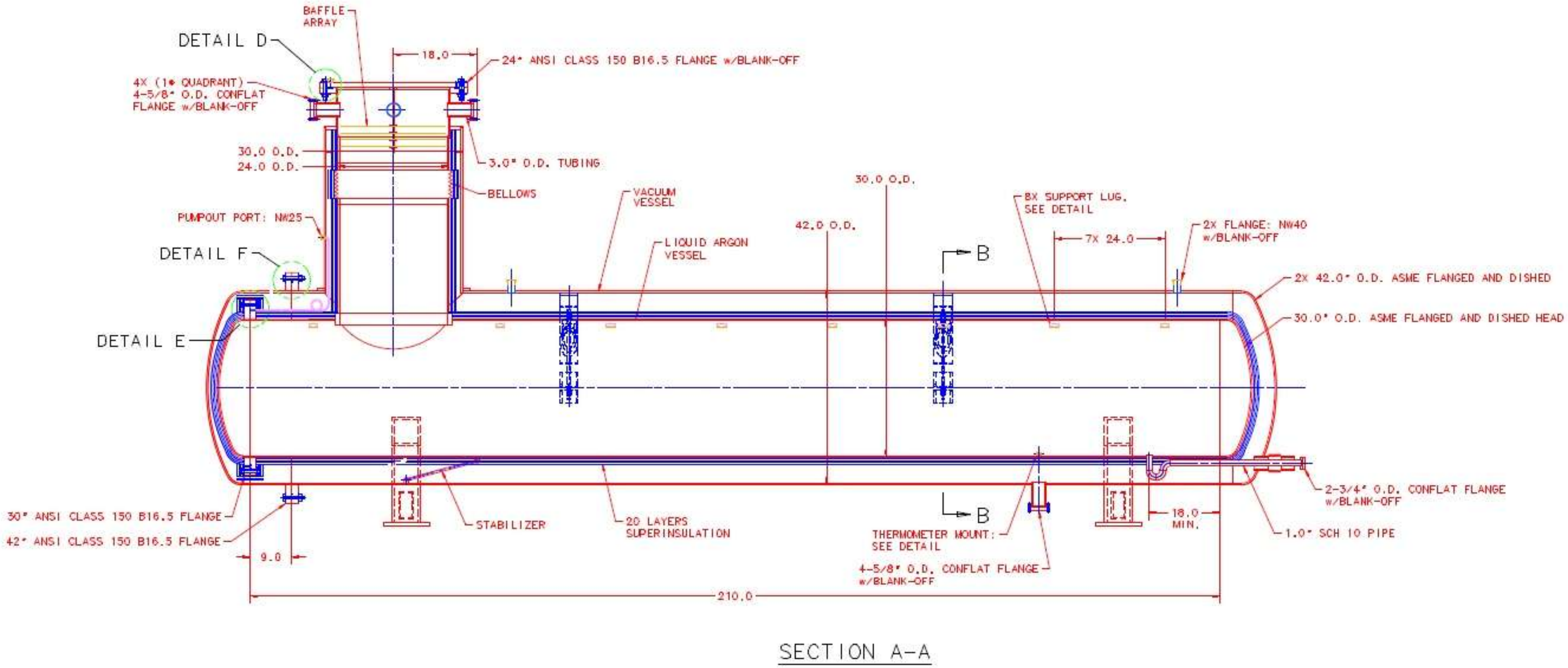
Test Samples Dewar

Material tests

setup for lifetime measurements (effect of materials and effectiveness of different filters) under assembly at Fermilab

5 m Drift Demonstration at Fermilab

Cryostat drawing for purchasing department



Long wires tests

- ***measurements of the mechanical properties of the wires both at room temperature and in LAr***
  - *100 μ and 150 μ Stainless Steel 304V*
- ***develop wire holders that work at cryogenic temperature and do not pollute LAr***
- ***determination of wire tension***
  - *electrostatic stability*
  - *restriction of sagittas*
  - *wire supports*
- ***study of noise on long wires***
  - *mechanical vibrations (i.e. induced by LAr flow)*
  - *measure damping effect of LAr on wire oscillations*
  - *study of electronics coupled to long wires (large input capacitance !)*

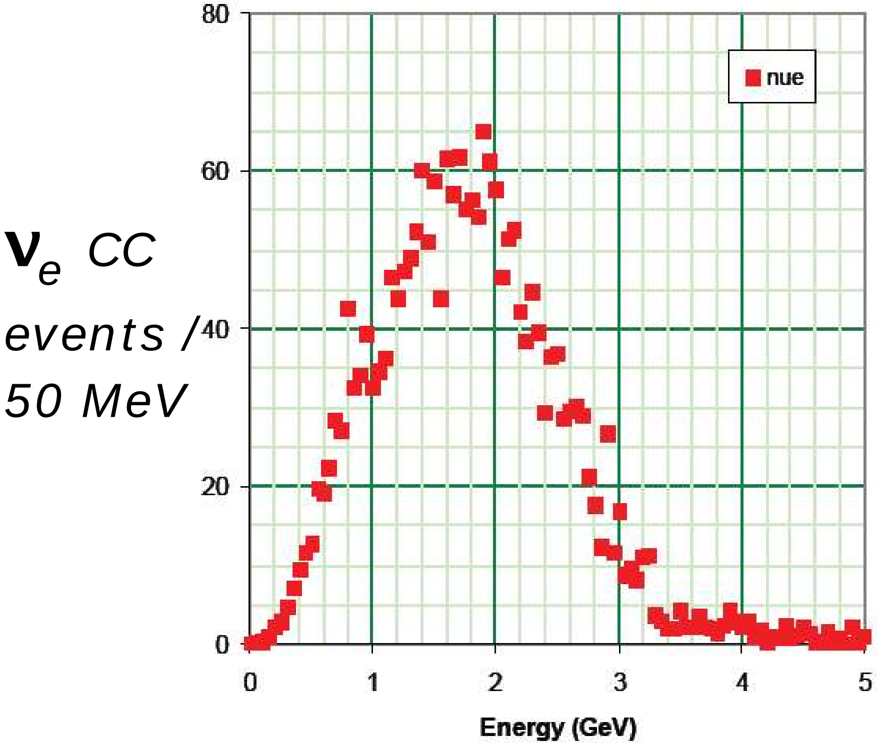
The "130 ton" detector (50 ton fiducial)

- ***Physics development using existing technology***
  - ***Establish successful technology transfer***
  - ***Record and reconstruct complete neutrino interactions (ν_μ and ν_e NC and CC) on the surface in the presence of cosmic rays***
  - *Establish physics collaboration by:*
    - *Developing event identification*
    - *Developing reconstruction*
    - *Developing analysis*
  - ***Measure ν interactions in the quasi-elastic and resonance region***

Where to find 2 GeV electron neutrinos ?

Electron Neutrinos in MINOS Surface Building

From the NOvA Proposal March 15, 2005



- *The charged current ν_e event spectrum in the MINOS surface building.*
- *The ν_e event spectrum peaks just below 2 GeV.*
- *There are ~2,000 ν_e events shown here for 6.5E20 POT and the 20.4 ton fiducial mass NOvA near detector.*

NuMI is presently providing ~2E20 POT per year.

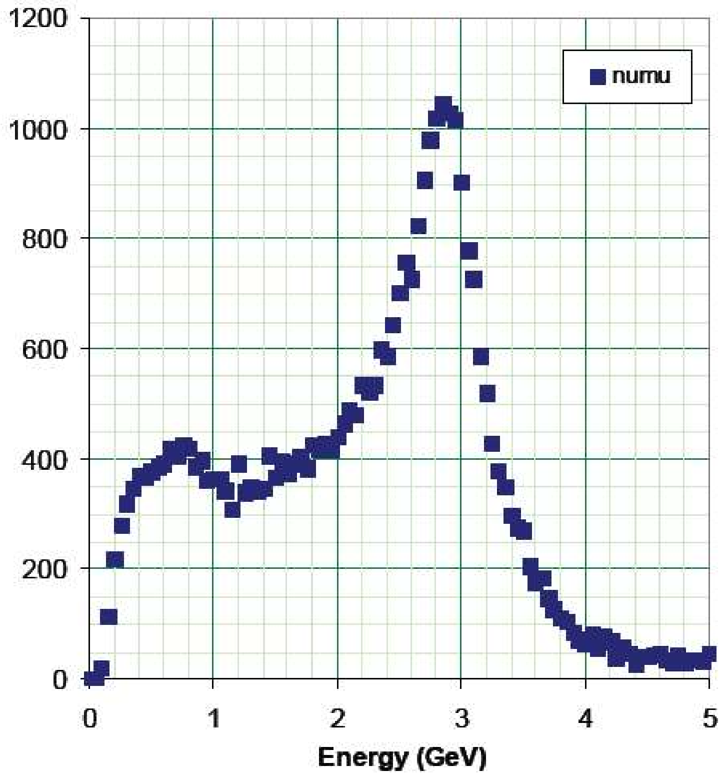
The 130 ton LArTPC has a 50 ton fiducial mass.

- ***the LAr TPC detector would get ~1600 ν_e events/year.***

Muon Neutrinos in MINOS Surface Building

From the NOvA Proposal March 15, 2005

ν_μ *CC events / 50 MeV*



- *Same assumptions as previous slide, except this shows ~15,000 muon neutrinos.*
- *The* ν_μ *peak at ~2.8 GeV is from Kaon decay.*

- ***the LAr TPC detector would get ~34000 νCC events/year***

~10000 ν_μ CC events/year in the peak between 2.4 and 3.2 GeV

The "1 kton" tank

- ***Engineering Development to demonstrate scalability to large tank***

  - ***Construction of tank with the same techniques to be used with the large tank***
  - ***Demonstrate argon purity with the same techniques to be used with the large tank***
  -
  - ***Mechanical integrity of TPC***
  - ***Readout signal / noise***
  - ***Microphonics due to argon flow***

  - ***Uncover whatever surprises there may be***

LArTPC's report to NuSAG*

www-lartpc.fnal.gov

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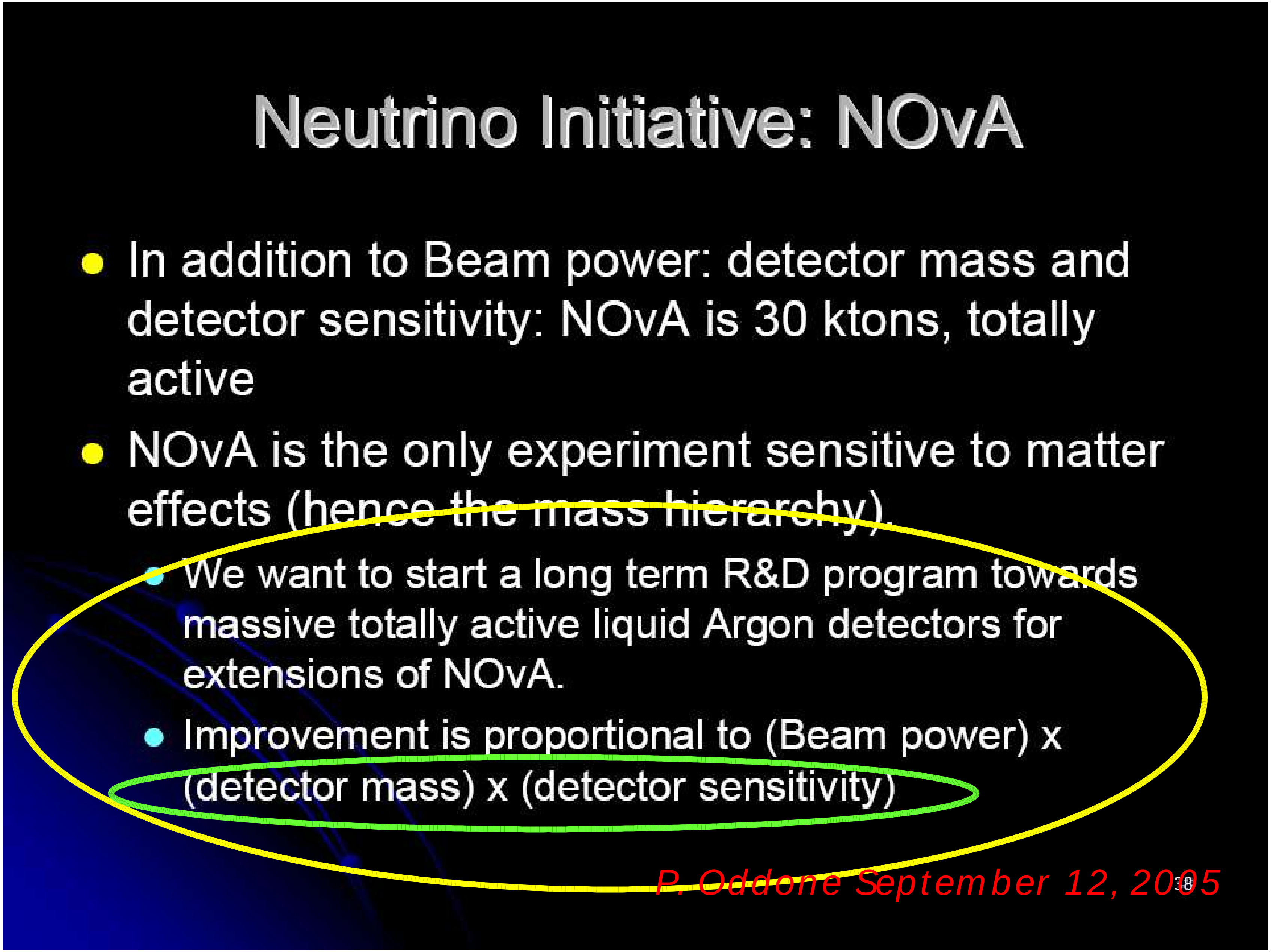


growing support from university groups as well.......

Conclusions

Liquid Argon TPC detectors are great tools for low energy neutrino physics

~1kton scale detectors have been successfully built by ICARUS

There is a path towards adressing R&D questions for realizing massive LArTPCs.

We have great new neutrino sources -- we should couple these with great detectors!

Capability depends on δ and θ_{13}

The CP Violation Parameter

Three Neutrino Mixing Matrix:

$$U = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix}$$

$$= \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

From Atmospheric and Long Baseline Disappearance Measurements

From Reactor Disappearance Measurements

From Long Baseline Appearance Measurements

From Solar Neutrino Measurements

Chooz limit is
$\sin^2 2\theta_{13} \sim 0.1$

Given very high ν_e efficiency and NC background rejection well below ½ of the intrinsic ν_e beam backgrounds, how sensitive are these detectors?

↓

Sensitivity =
detector mass x
detector efficiency x
protons on target/yr x
# of years

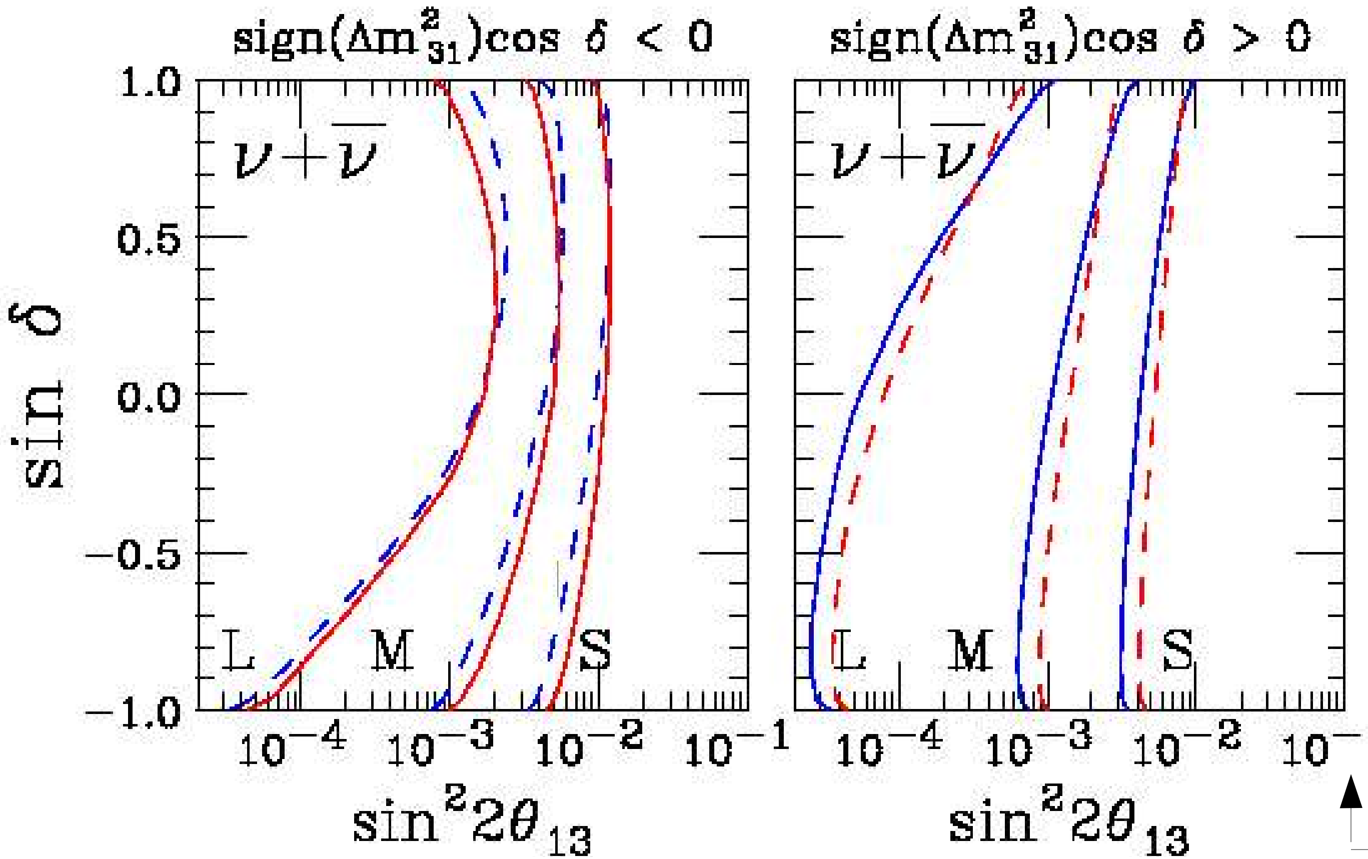
As an example: focus on recent paper by Mena and Parke

hep-ph/0505202

	<u>S</u>mall	<u>M</u>edium	<u>L</u>arge
NOvA	30kTon	30kton + PD or x5 mass or exposure	30kton + PD + x5 mass or exp.
LArTPC (90% ν_e eff.)	8kton	40kton	40kton + PD or exposure

All sensitivities assume 3 years running each in ν and $\bar{\nu}$ mode

Sensitivity to CP phase(sin δ) vs $\sin^2 2\theta_{13}$ for



CHOOZ limit

most restrictive:
cos δ <0, normal hierarchy
cos δ >0, inverted hierarchy

least restrictive:
cos δ >0, normal hierarchy
cos δ <0, inverted hierarchy

Efficiency and Rejection study

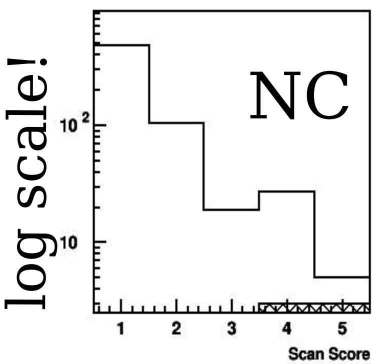
Analysis was based on a blind scan of 450 events, carried out by 4 undergraduates with additional scanning of “signal” events by experts.

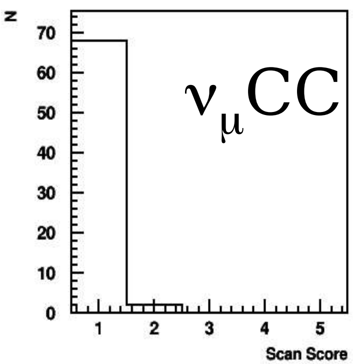
- Neutrino event generator: NEUGEN3. Used by MINOS/NOvA collaboration. Hugh Gallagher (Tufts) is the principal author.
- GEANT 3 detector simulation: trace resulting particles through a homogeneous volume of liquid argon. Store energy deposits in thin slices.

Training samples:

50 events each of ν_eCC, ν_μCC and NC

- individual samples to train
- mixed samples to test training

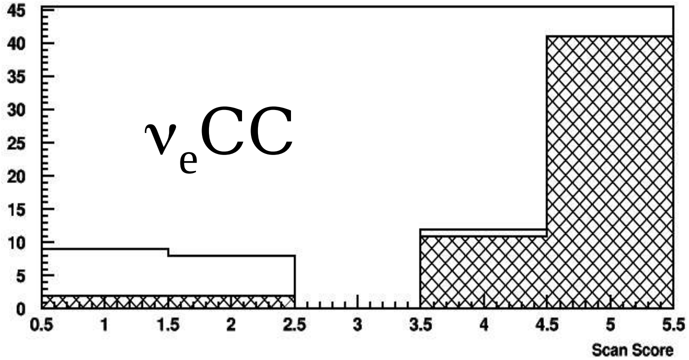




Blind scan of 450 events scored from 1-5 with

- signal=5
- background=1

plain region: students
Hatched region: experts

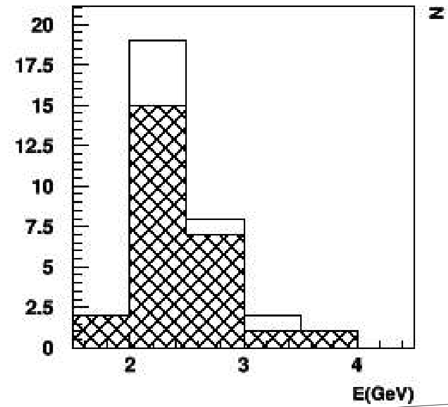


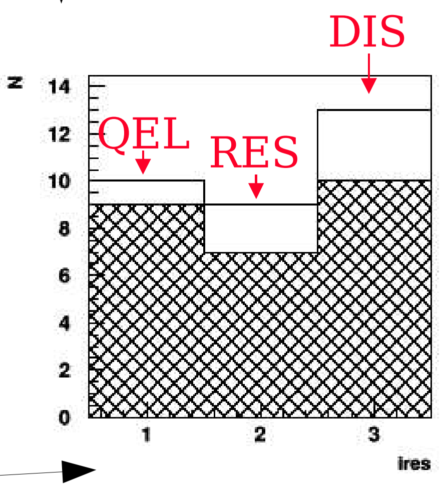
Tufts University Group

Overall efficiencies, rejection factors,
and dependencies

	N	pass	ε	η
NC	290	4	-	72.5
signal ν_e	32	26	0.81	-
Beam ν_e: CC	24	14	0.58	-
NC	8	0	-	

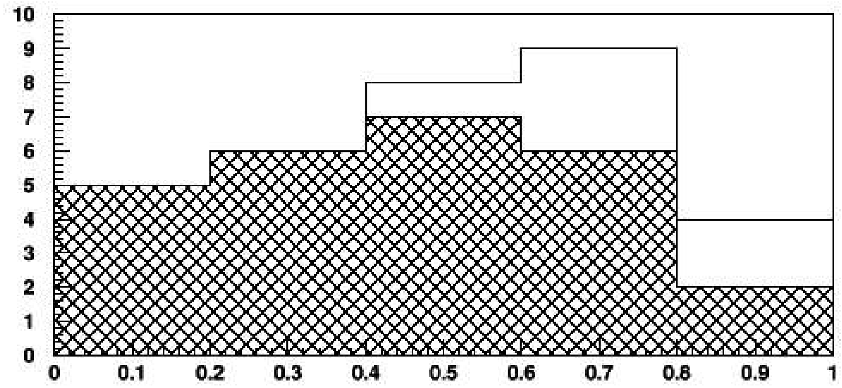
Signal ν_e:





Efficiency is substantial even for high multiplicity events

Efficiency is ~100% for y<0.5, and ~50% above this



$y = E_{had}/E_\nu$